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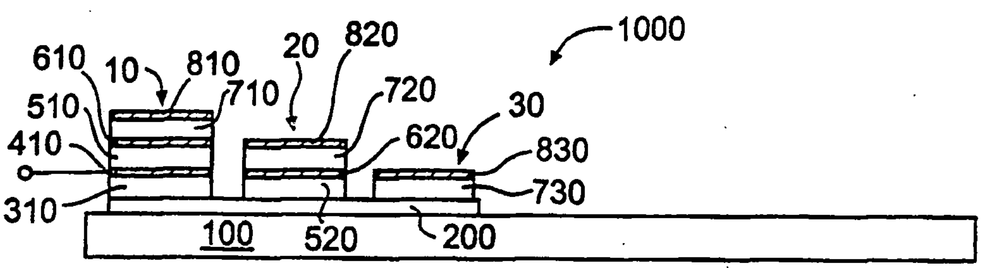

(57) Abstract

Laser radiation may be used to ablate organic materials (310, 520 and 730) as well as metals (400, 600 and 800). A method of using such laser ablation to selectively remove organic material and metal material from an organic light emitting device (OLED) work piece (1000) is disclosed. The ablation enables fabrication of multi-color pixels in OLED displays. A novel OLED structure having adjacent multi-colored organic stakes (10, 20 and 30) is disclosed. Further, a novel ablation chamber (900) in which an OLED structure (1000) may be subjected to laser ablation is also disclosed. The ablation chamber includes means for moving an OLED structure within the chamber, means for detecting an ablation endpoint, and means for suctioning ablated material from the chamber.

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LASER ABLATION METHOD TO FABRICATE COLOR ORGANIC LIGHT EMITTING DIODE DISPLAYS

Cross Reference To Related Patent Application

This application relates to and claims priority on a provisional application (unassigned) filed July 11, 1997 and entitled "Laser Ablation Method To Fabricate Color Organic Light Emitting Diode Displays".

Field of the Invention

The invention relates to organic light emitting devices having multi-colored pixels and apparatus and methods for making such devices.

Background of the Invention

Organic light emitting devices (OLED's) may be used to provide displays. The displays may comprise a collection of light emitting diodes that are arranged into picture elements (pixels). In order to provide a full color display, it is desirable to make OLED's with multi-color pixels, or more specifically with red, blue and green subpixels.

In order to produce an OLED with red, blue and green subpixels, it may be necessary to employ lithographic processing techniques to build the red, green and blue subpixels. It may be difficult, if not impossible, however, to practice the required lithographic techniques without introducing some small amount of water into the OLED. Unfortunately, OLED's are extremely sensitive to the presence of water and oxygen. Small amounts of moisture, on the order of parts per billion, can cause significant degradation in the performance of the display. This sensitivity to water may pose a serious challenge to OLED manufacturers who wish to make multi-colored OLED displays.

One potential alternative to lithographic processing involves the use of shadow masks during evaporation of the organic layers in the OLED. The mechanical strength of the shadow mask limits the fineness of the mask, however, the process of using a shadow mask does have the advantage of being water free. The limitation on the fineness

of the pattern, in turn, limits the resolution of the subpixels produced with the shadow mask. Consequently, the subpixels that may be attained using a shadow mask are larger than those that may be attained using other processing methods because of the limitation on the fineness of the mask. The same limitation on subpixel size (*i.e.* display resolution) may result from the use of dry etch processes, such as plasma and RIE processes. Thus, the display resolution attained using water-free processing techniques may be less than desirable.

One solution to the foregoing problems has been to make a single color OLED display and convert it to a multi-color display by using color filters and/or color conversion from a shorter wavelength. These OLED's may be very inefficient, and therefore undesirable, because a large fraction of the emitted light from a filtered or converted subpixel may be lost. The addition of filters and converters may also complicate manufacturing of the OLED by adding the need for extra processing steps.

Based upon the limitations that may result from using an OLED with filters or converters, applicant believes that the use of individual color emitters forming red, green, and blue subpixels may be the preferred method of providing multi-colored OLED displays. Accordingly, there is a need for an OLED, and a method of making the OLED, in which the use or production of water is reduced. Further, there is a need for an OLED and method in which the smallness in size of the subpixels is not undesirably limited.

The foregoing needs may be met by applicant's laser ablation method to fabricate color organic light emitting diode displays. Techniques for laser ablation are disclosed in U.S. Patent No. 4,925,523 (May 15, 1990) to Braren et al., and U.S. Patent No. 5,232,549 (Aug. 3, 1993) to Cathey et al., each of which are hereby incorporated by reference herein.

Objects of the Invention

It is therefore an object of the present invention to provide an OLED that is less likely to include water.

It is another object of the present invention to provide a method of making an OLED which reduces the likelihood of water being included in the OLED.

It is a further object of the present invention to provide an OLED and method of making the same, that includes subpixels of a desirable size for a high resolution display.

It is still another object of the present invention to provide an OLED with individual red, blue and green subpixels.

It is yet another object of the present invention to make an OLED using laser ablation.

It is still yet another object of the present invention to provide a laser ablation system for making an OLED.

It is still a further object of the invention to detect the ablated material in an OLED work piece by detecting material fluorescence.

Additional objects and advantages of the invention are set forth, in part, in the description which follows and, in part, will be apparent to one of ordinary skill in the art from the description and/or from the practice of the invention.

Summary of the Invention

In response to the foregoing challenge, Applicant has developed an innovative organic light emitting device comprising: a support substrate; a transparent hole injector layer overlying said substrate; and spaced first and second subpixel stacks overlying said hole injector layer, wherein: said first subpixel stack comprises (1) an active lower layer that is capable of producing a first color of light and is overlying the hole injector layer, and (2) a first conductor layer overlying the active lower layer capable of producing the first color of light, and said second subpixel stack comprises (1) an active lower layer that is capable of producing a second color of light and is overlying the hole injector layer, (2) a second conductor layer overlying the active lower layer capable of producing the second color of light, and (3) an inactive upper layer overlying the second conductor layer, said inactive upper layer being comprised of the same material as that of the active lower layer of the first subpixel stack.

Applicant has also developed an innovative method of providing light emitting subpixels in an organic light emitting device comprising the steps of: providing a substrate with an overlying hole injector layer; providing a lower layer of organic

material on the hole injector layer; providing an upper layer of electrically conductive material overlying the lower layer; and selectively ablating portions of the lower and upper layers such that a portion of the hole injector layer is exposed and light emitting subpixels are formed from a remaining strip of electrically conductive material overlying a strip of organic material.

More specifically, in a method of forming an organic light emitting device having subpixel strips that include organic and hole injector material and that are adapted to emit light of different wavelengths, applicant has developed the improvement comprising the step of selectively ablating organic and hole injector material from said device in order to form said subpixel strips.

Applicants have further developed an innovative laser ablation system comprising: a chamber for isolating a work piece in a controlled ambient; means for controlling the amount of moisture in said chamber; means for controlling the location of a work piece in said chamber; means for focusing laser light on a work piece in said chamber; means for detecting the location of ablated material on said work piece in said chamber; and means for removing ablated material from said chamber.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only, and are not restrictive of the invention as claimed. The accompanying drawings, which are incorporated herein by reference, and which constitute a part of this specification, illustrate certain embodiments of the invention, and together with the detailed description serve to explain the principles of the present invention.

Brief Description of the Drawings

Figs. 1-7 are cross-sectional views in elevation that illustrate sequential steps in the formation of an OLED embodiment of the invention.

Fig. 8 is a flow chart that illustrates the process steps of a method embodiment of the invention.

Fig. 9 is a pictorial view of an ablation chamber embodiment of the invention that may be used to make an OLED.

Figs. 10-12 are cross-sectional views in elevation that illustrate sequential steps in the formation of an OLED in accordance with an alternative embodiment of the invention.

Detailed Description of the Preferred Embodiments

Reference will now be made in detail to a preferred embodiment of the present invention, an example of which is illustrated in the accompanying drawings. A preferred method of making an OLED is illustrated by the sequence of process steps shown in Figs 1-7.

With reference to Fig. 7, the completed OLED may include multiple red **10**, green **20**, and blue **30** stacks patterned on parallel strips of hole injector material **200** overlying a substrate **100**. The red stack **10** may comprise an active lower red subpixel strip **310**, a first strip of electron injector material **410** overlying the lower strip **310**, an inactive green subpixel strip **510** overlying the first strip of electron injector material **410**, a second strip of electron injector material **610** overlying the inactive green subpixel strip **510**, an inactive upper blue subpixel strip **710** overlying the second strip of electron injector material **610**, and a third strip of electron injector material **810** overlying the inactive blue subpixel strip **710**.

The green subpixel stack **20** may comprise an active lower green subpixel strip **520**, a fourth strip of electron injector material **620** overlying the green strip **520**, an inactive upper blue subpixel strip **720** overlying the fourth strip of electron injector material **620**, and a fifth strip of electron injector material **820** overlying the inactive blue subpixel strip **720**.

The blue subpixel stack **30** may comprise an active blue subpixel strip **730** and a sixth strip of electron injector material **830** overlying the active blue subpixel strip **730**. It is appreciated that the color of the active lower layer in each stack (**10**, **20**, and **30**) can be varied without departing from the scope of the invention. For example, stack **10** may include an active lower layer of green material, or of blue material, in alternative embodiments of the invention.

The completed OLED of Fig. 7 may be made according to the process illustrated by Figs. 1-6. Figure 1 is a cross-sectional view of an OLED substrate **100** with one or more hole injector strips **200** (preferably transparent indium tin oxide (ITO)) patterned thereon. In the alternative, hole injector strips **200** may be indium zinc oxide (IZO). The substrate **100** may be a transparent and rigid material, such as glass, that is capable of supporting the overall device **1000** when completed. The ITO strips **200** may be formed on the substrate **100** by wet etching using photolithic methods or by laser ablation. The ITO strips **200** may run across the substrate **100** (left to right as shown in Fig. 1) and may have a width that is appropriate for the width of a pixel and a thickness in the range of 0.05 to 0.15 microns.

With reference to Fig. 2, one or more lower layers **300** of organic material that are capable collectively of producing a first color of light may be provided on the ITO strip **200**. For example, if the first color of light is chosen to be in the red wavelengths, lower layers **300** may comprise a stack of CuPc (copper pthalocyanine), NPB (4,4′-bis[N-(1-naphthyl)-N-phenyl-amino]-biphenyl), and Alq (aluminum hydroxy quinolene). A layer of electron injector material **400**, which may be an electrical conductor (*e.g.* MgAg), may be provided overlying or on top of the lower layers **300**. The electron injector material **400** may be deposited using an evaporation process and be in the range of 0.2 to 1.0 microns thick when completed.

With reference to Fig. 3, a high power laser beam, such as an excimer laser, may be used to ablate the electron injector layer **400** and the red layer **300** in selected regions so as to produce a strip of red subpixels **310** and electron injector material **410** (running into the page as shown in Fig. 3) in the red stack **10**. Depending on the wavelength of the laser and the optics design, the laser beam can be focused to submicron size to form the red subpixels in a very thin strip if desired.

In order to detect the point of ablation at which the ITO strip **200** is reached, a light detector may be used. Ablation of the organic red layer **300** produces a visible light fluorescence. Ablation of the ITO strip **200**, however, does not produce significant fluorescence. Thus, the ablation point at which the ITO strip 200 is reached may be determined by detecting a decrease or ceasing of fluorescence. The point at which the

ITO strip 200 is reached may be fairly accurately determined because the ablation is preferably carried out in pulses, which allows the level of fluorescence to be measured after each pulse.

With reference to Fig. 4, one or more intermediate layers **500** of organic material that are capable collectively of producing a second color of light (*e.g.* green) may be provided on the ITO strip **200** and the red stack **10**. A second layer of electron injector material **600** may be provided overlying or on top of the intermediate layers **500**. Selective laser ablation may be carried out on the intermediate layers **500** and the second layer of electron injector material **600** to produce the structure shown in Fig. 5. The ablation may be used to create a small gap (on the order of 2.0 microns) between the red stack **10** and the green stack **20**.

With reference to Fig. 5, the red stack **10** comprises an active lower red subpixel strip **310**, a first strip of electron injector material **410** overlying the lower red strip **310**, an inactive green subpixel strip **510** overlying the first strip of electron injector material **410**, and a second strip of electron injector material **610** overlying the inactive green subpixel strip **510**.

With continued reference to Fig. 5, the green stack **20** may comprise an active lower green subpixel strip **520** and a fourth strip of electron injector material **620** overlying the lower green strip **520**.

With reference to Fig. 6, one or more upper or top layers **700** of organic material that are capable collectively of producing a third color of light (*e.g.* blue) may be provided on the ITO strip **200**, the red stack **10** and the green stack **20**. A sixth layer of electron injector material **800** may be provided overlying or on top of the upper layers **700**. Selective laser ablation may be carried out on the upper layers **700** and the sixth layer of electron injector material **800** to produce the structure shown in Fig. 7.

With reference to Fig. 7, the completed OLED may include a red stack **10**, a green stack **20** and a blue stack **30**. The red stack may comprise an active lower red subpixel strip **310**, a first strip of electron injector material **410**, an inactive green subpixel strip **510**, a second strip of electron injector material **610**, an inactive upper blue subpixel strip **710**, and a third strip of electron injector material **810**. The green stack **20** may comprise

an active lower green subpixel strip **520**, a fourth strip of electron injector material **620**, an inactive upper blue subpixel strip **720**, and a fifth strip of electron injector material **820**. The blue subpixel stack **30** may comprise an active blue subpixel strip **730** and a sixth strip of electron injector material **830**.

With continued reference to Fig. 7, in operation of the completed OLED **1000**, voltage may be applied only to the bottom most electron injector strips (*i.e.* first strip **410**, fourth strip **620**, and sixth strip **830**) in each of the respective subpixel stacks **10**, **20**, and **30**. The intermediate and upper electron injector strips (*i.e.* second strip **610**, third strip **810**, and fifth strip **720**) may be shorted with the bottom most electron injector strips in order to avoid complications of unconnected floating electrodes.

The lower most subpixel strip in each subpixel stack will define the color emitted by the stack. The emission spectrum of the strips of organic layer in contact with the ITO layer may not be impacted by the other organic layers on top of it, because there are no hole injectors available to the upper organic layers. For example, with reference to Fig. 7, the red stack **10** may only emit red light because the red subpixel layer is the only layer which contacts both an electron injector strip (first strip **410**) and a hole injector strip (ITO strip **200**). The green strip **510** and the blue strip **710** in the red stack **10** may not emit light because there is no hole injector (ITO) in contact with these strips. In like manner, the green stack **20** may only emit green light, and the blue stack **30** may only emit blue light.

Each of the strips of electron injector material (**410**, **610**, **810**, **620**, **820**, and **830**) may be provided by a strip of Mg/Ag metal. One advantage of using this particular type of metal is that it provides a reflective surface adjacent to the lower most red, green, and blue strips (**310**, **520**, and **730**). The strips of electron injector material **410**, **620**, and **830** may prohibit light from entering the upper layers of the organic stacks **10**, **20**, and **30**, thereby reducing light loss and unwanted color noise. In addition, the reflective metal surfaces may reflect most or all of the light generated in the lower most active strips back to the viewing side of a display, thereby enhancing display brightness.

In an alternative embodiment of the invention, the completed OLED of Fig. 7 may be made according to the process illustrated by Figs. 10-12. Figure 10 is a cross-

sectional view of an OLED substrate **100** with one or more hole injector strips **200** (preferably transparent indium tin oxide (ITO)) patterned thereon, one or more lower layers **300** of organic material capable collectively of producing a first color of light overlying the ITO strip **200**, and a layer of electron injector material **400** overlying the lower layers **300**.

With reference to Fig. 11, a high power laser beam, such as an excimer laser, may be used to ablate the electron injector layer **400** in selected regions so as to produce a strip of electron injector material **410** (running into the page as shown in Fig. 11). Depending on the wavelength of the laser and the optics design, the laser beam can be focused to submicron size to form the electron injector material into a very thin strip.

With reference to Fig. 12, a thin strip of organic material **310** may be formed under the strip of electron injector material **410** using an etching process (preferably - oxygen plasma etching). The electron injector material **410** may be used as an etch mask so that the strip of organic material **310** is coextensive with the electron injector material **410**.

The foregoing process, explained with reference to Figs. 10-12, may be used to produce additional organic stacks (not shown) next to the stack **10**, just as the process explained with reference to Figs. 1-7 may be repeated to form stacks **10**, **20**, and **30**.

A laser ablation system embodiment of the invention, which is useful for making the OLED of the invention, is shown in Fig. 9. The system may comprise a gas tight chamber **900**, a translation stage **910** within the chamber, a laser ablation detector **920**, an optics subsystem **930**, an ambient fill port **940**, a suction port **950**, and a laser beam input port **960**.

The chamber **900** may be used to isolate an OLED work piece **1000** in a controlled ambient environment for the laser ablation process. For example, an inert gas, such as Argon or Nitrogen, may be introduced into the chamber **900** through the ambient fill port **940** to provide an ambient of inert gas around the work piece **1000**. The introduction of inert gas through the fill port **940** may provide a means for reducing the amount of moisture and oxygen in the chamber **900** during processing as well as helping the suction process to remove the ablated debris.

The work piece **1000** may be supported on and secured to the translation stage **910** within the chamber **900** during laser ablation processing. The stage **910** may provide a means for controlling the location of the work piece **1000** relative to the laser beam **962** and may include one or more servo motors **912** for translating the stage in one, two, or three dimensions. The stage **910** may be translated in the x-y plane in order to scan a stationary laser beam **962** across the work piece **1000**. The stage **910** may be translated in the z direction in order to focus the laser beam **962** on the work piece **1000**.

A laser (not shown) may be located outside the chamber **900** and may provide a laser beam **962** that is coupled into the chamber through a first set of optics located at the laser beam input port **960**. Once inside the chamber **900**, the laser beam **962** may be directed and focused on the work piece **1000** held on the translation stage **910** using the optics subsystem **930**. The optics subsystem **930** may include numerous optical elements, such as mirror(s) **932** and lens(es) **934** and thus may provide means for focusing laser light on the work piece **1000**. The optics subsystem **930** may also include a mask and projection optics with appropriate reduction factors.

The chamber **900** may include a detector **920** that is capable of detecting the composition of ablated material on the work piece **1000**. Preferably, the detector **920** may be fixed to the chamber **900**. If laser ablation is carried out by translating the stage **910** or by means of a projection mask, then the detector may be directed to a fixed location, because the intersection of the laser beam **962** and the work piece are fixed relative to the detector.

In an alternative embodiment, ablation may be carried out by scanning the laser beam **962** across a fixed position work piece **1000** by adjusting the optics subsystem **930**. If laser ablation is carried out by scanning the laser beam **962** across a stationary work piece, then the detector **920** may be adapted to scan in coordination with the laser beam.

The detector **920** may provide signals that indicate the presence of ablated material to a controller (not shown). Responsive to the receipt of such signals from the detector **920**, the controller may adjust the location of ablation by moving the translation stage **910** or the laser beam **962**. The detector may operate by detecting the fluorescence of ablated organic material. Ablation is a photochemical effect which may produce

fluorescence in the UV to visible light range in organic material. The ablation of organic material (such as the material comprising red strip **310**, green strip **520**, and blue strip **730** of Fig. 7) accordingly may produce light. Conversely, the ablation of ITO material produces very little, if any, fluorescent light. The detector **920** may be used to monitor the characteristic fluorescence emission from various layers of polymers or metals in the work piece **1000** during ablation. An abrupt change in characteristic fluorescence intensity may indicate the ablation endpoint. The detector **920** may include a filter in front of the detector that prevents ablating laser light from being detected.

By detecting the emission of light, or the lack thereof, in the ablation region, the detector **920** may be used to determine the point in the ablation process at which the layer of ITO material is reached. By applying the laser beam to the work piece **1000** in discrete pulses, the precise transition point between organic material and ITO material may be detected. Because it is desirable to ablate down to, but not into, the ITO material, the foregoing process is very useful in controlling the depth of ablation.

The type of detector **920** that is used may be very sensitive; *e.g.* capable of detecting the emission of a few photons at a time. Such detectors have been used in a limited fashion to detect ablation end points when ablating plaque on the interior wall of an artery.

The chamber **900** may also include one or more suction devices **952** for removing ablated material from the chamber. The suction device **952** may be introduced into the chamber through a suction port **950**. The suction may be provided by means of a suction pump such as a Turbo pump, which would not contaminate the chamber by back-streaming of oil, etc.

The ablation of selective portions of the OLED to leave the red, green and blue subpixel stacks (**10**, **20**, and **30**, Fig. 1) may be carried out in the above described chamber **900** using pulsed laser beam(s) of one or more wavelengths. One embodiment of the ablation method of the invention is described with reference to the flow chart shown in Fig. 8 and the ablation system of Fig. 9.

First, in accordance with step **1100** of Fig. 8, the work piece, which includes a substrate to be coated with organic material, may be loaded into a deposition chamber.

In step **1110**, the work piece may be coated with ITO, organic, and electron injector material in the appropriate patterns consistent with the steps illustrated by Figs. 1-2. In step **1120** the work piece may be unloaded from the deposition chamber. In step **1130** the work piece may be secured to the translation stage within the laser ablation chamber. The laser ablation chamber then may be sealed and filled to a nominal pressure of 1.0 to 1.1 atmospheres with an inert gas, such as Argon or Nitrogen. Laser ablation and the suctioning of ablated material may then be carried out consistent with the step illustrated by Fig. 3. In step **1140** the same deposition chamber referenced above, or a different chamber, may be loaded. In step **1150** the work piece may be coated with second layers of organic and electron injector material in the appropriate patterns consistent with the step illustrated by Fig. 4. In step **1160** the work piece may be unloaded from the deposition chamber. Returning to step **1130**, the work piece may be secured again to the translation stage within the laser ablation chamber; the laser ablation chamber may be sealed and filled with an inert gas; and the required laser ablation may be carried out consistent with the step illustrated by Fig. 5. In step **1170** the deposition chamber may be loaded for a third time. In step **1180** the work piece may be coated with third layers of organic and electron injector material in the appropriate patterns consistent with the step illustrated by Fig. 6. In step **1190** the work piece may be unloaded from the deposition chamber.

It will be apparent to those skilled in the art that various modifications and variations can be made in the construction, configuration, and/or operation of the present invention without departing from the scope or spirit of the invention. For example, in the embodiments mentioned above, various changes may be made in the order and selection of light emitting organic materials without departing from the scope and spirit of the invention. Further, it may be appropriate to make additional modifications or changes to the system used to ablate the work piece and the system used to detect the ablation end point without departing from the scope of the invention. Thus, it is intended that the present invention cover the modifications and variations of the invention provided they come within the scope of the appended claims and their equivalents.

I CLAIM:

1. An organic light emitting device comprising:

a support substrate;

a transparent hole injector layer overlying said substrate; and

spaced first and second subpixel stacks overlying said hole injector layer, wherein:

said first subpixel stack comprises (1) an active lower layer that is capable of producing a first color of light and is overlying the hole injector layer, and (2) a first conductor layer overlying the active lower layer capable of producing the first color of light, and

said second subpixel stack comprises (1) an active lower layer that is capable of producing a second color of light and is overlying the hole injector layer, (2) a second conductor layer overlying the active lower layer capable of producing the second color of light, and (3) an inactive upper layer overlying the second conductor layer, said inactive upper layer being comprised of the same material as that of the active lower layer of the first subpixel stack.

2. The device of Claim 1 wherein the transparent hole injector layer comprises a material selected from the group consisting of indium tin oxide and indium zinc oxide.

3. The device of Claim 1 wherein the first and second colors of light are selected from the group consisting of: red, blue, and green.

4. The device of Claim 1 wherein the first conductor layer includes a reflective surface in contact with the active lower layer capable of producing the first color of light.

5. The device of Claim 1 wherein the first conductor layer comprises a thin strip of conductive material.

6. The device of Claim 1 wherein the hole injector layer comprises a thin strip of conductive material.

7. The device of Claim 1 wherein the second subpixel stack further comprises a third conductor layer overlying the inactive upper layer capable of producing the first color of light; and the device further comprises a third subpixel stack having (1) an active lower layer that is capable of producing a third color of light overlying the hole injector

layer, (2) a fourth conductor layer overlying the active lower layer capable of producing the third color of light, (3) an inactive intermediate layer overlying the fourth conductor layer, said inactive intermediate layer being comprised of the same material as that of the active lower layer of the second subpixel stack, (4) a fifth conductor layer overlying the inactive intermediate layer, (5) an inactive top layer overlying the fifth conductor layer, said inactive top layer being comprised of the same material as that of the active lower layer of the first subpixel stack, and (6) a sixth conductor layer overlying the inactive top layer.

8. An organic light emitting device comprising:

a transparent support substrate;

a transparent strip of indium tin oxide overlying said substrate; and

spaced first, second, and third subpixel stacks overlying said hole injector layer, wherein:

said first subpixel stack comprises (1) an active lower layer that is capable of producing a first color of light and is overlying the hole injector layer, and (2) a first conductor layer overlying the active lower layer capable of producing the first color of light,

said second subpixel stack comprises (1) an active lower layer that is capable of producing a second color of light and is overlying the hole injector layer, (2) a second conductor layer overlying the active lower layer capable of producing the second color of light, (3) an inactive upper layer overlying the second conductor layer, said inactive upper layer being comprised of the same material as that of the active lower layer of the first subpixel stack, and (4) a third conductor layer overlying the inactive upper layer capable of producing the first color of light, and

said third subpixel stack comprises (1) an active lower layer that is capable of producing a third color of light overlying the hole injector layer, (2) a fourth conductor layer overlying the active lower layer capable of producing the third color of light, (3) an inactive intermediate layer overlying the fourth conductor layer, said inactive intermediate layer being comprised of the same material as that of the active lower layer of the second subpixel stack, (4) a fifth conductor layer overlying the inactive

intermediate layer, (5) an inactive top layer overlying the fifth conductor layer, said inactive top layer being comprised of the same material as that of the active lower layer of the first subpixel stack, and (6) a sixth conductor layer overlying the inactive top layer,

wherein said first, second and fourth conductor layers each include a light reflective surface.

9. An organic light emitting device comprising:

a support substrate;

a transparent hole injector layer overlying said substrate; and

spaced first and second subpixel stacks overlying said hole injector layer,

wherein said first subpixel stack comprises (1) a lower layer of a first type of organic material overlying and contacting said hole injector layer, and (2) an upper layer of a second type of organic material overlying said lower layer, and

wherein said second subpixel stack comprises a lower layer of the second type of organic material overlying and contacting said hole injector layer.

10. A method of providing light emitting subpixels in an organic light emitting device comprising the steps of:

providing a substrate with an overlying hole injector layer;

providing a lower layer of organic material on the hole injector layer;

providing an upper layer of electrically conductive material overlying the lower layer; and

selectively ablating portions of the lower and upper layers such that a portion of the hole injector layer is exposed and light emitting subpixels are formed from a remaining strip of electrically conductive material overlying a strip of organic material.

11. The method of Claim 10 wherein the step of selectively ablating comprises laser ablation.

12. The method of Claim 10 wherein the step of selectively ablating comprises pulsed laser ablation.

13. The method of Claim 10 wherein the step of selectively ablating comprises laser ablation at more than one wavelength.

14. The method of Claim 10 further comprising the step of providing the substrate with overlying hole injector, lower, and upper layers in an ablation chamber having a controlled atmosphere.

15. The method of Claim 14 further comprising the step of providing the ablation chamber with a vacuum atmosphere.

16. The method of Claim 14 further comprising the step of providing the ablation chamber with an inert gas atmosphere.

17. The method of Claim 10 further comprising the step of suctioning ablated material during the step of selectively ablating.

18. The method of Claim 10 further comprising the steps of:

monitoring fluorescence emission in the vicinity of ablation during the step of selectively ablating; and

controlling ablation responsive to changes in the monitored fluorescence emission.

19. The method of Claim 18 wherein the step of controlling ablation comprises the step of controlling the application of a laser beam to the substrate with overlying hole injector, lower, and upper layers.

20. The method of Claim 18 wherein the step of controlling ablation comprises the step of moving the substrate with overlying hole injector, lower, and upper layers.

21. The method of Claim 18 further comprising the step of filtering monitored fluorescence emission to reduce detection of laser light by a means for monitoring fluorescence emission.

22. The method of Claim 10 wherein the step of selectively ablating includes the step of selectively moving the substrate with overlying hole injector, lower, and upper layers.

23. A method of providing light emitting subpixels in an organic light emitting device comprising the steps of:

providing a substrate with an overlying hole injector layer;

providing a lower layer of organic material on the hole injector layer;

providing an upper layer of electrically conductive material overlying the lower layer;

providing the substrate with overlying hole injector, lower, and upper layers in an ablation chamber having a controlled atmosphere;

selectively ablating portions of the lower and upper layers with laser pulses such that a portion of the hole injector layer is exposed and light emitting subpixels are formed from a remaining strip of electrically conductive material overlying a strip of organic material;

suctioning ablated material during the step of selectively ablating;

monitoring fluorescence emission in the vicinity of ablation during the step of selectively ablating; and

controlling ablation responsive to changes in the monitored fluorescence emission.

24. A method of forming an organic light emitting device comprising the steps of:

providing a substrate with an overlying hole injector layer;

providing a first organic layer on the hole injector layer;

providing a first electron injector layer on the first organic layer;

selectively removing portions of the first organic and first electron injector layers to expose a portion of the hole injector layer and to form a first subpixel strip from a strip of first electron injector material overlying a strip of first organic material;

providing a second organic layer on the exposed portion of the hole injector layer and the first subpixel;

providing a second electron injector layer on the second organic layer; and

selectively removing portions of the second organic and second electron injector layers to re-expose a portion of the hole injector layer and to form a second subpixel strip spaced from and substantially parallel to the first subpixel strip.

25. The method of Claim 24 wherein the first and second organic layers are adapted to provide different wavelengths of visible light during operation of the organic light emitting device.

26. The method of Claim 24 further comprising the steps of:

providing a third organic layer on the re-exposed portion of the hole injector layer, the second subpixel strip and the first subpixel strip;

providing a third electron injector layer on the third organic layer; and

selectively removing portions of the third organic and third electron injector layers to form a third subpixel strip spaced from and substantially parallel to the second subpixel strip.

27. The method of Claim 24 wherein at least one of the first, second, and third electron injector layers comprises metal.

28. The method of Claim 24 wherein the hole injector layer comprises indium tin oxide.

29. The method of Claim 24 wherein said steps of selectively removing comprise steps of laser ablation.

30. The method of Claim 29 wherein the laser ablation steps comprise the steps of:

providing the device substrate on a moveable stage within an ablation chamber;

providing laser light to a focusing system in the ablation chamber;

selectively ablating material on the device with laser light received from the focusing system; and

suctioning ablated material away from the device.

31. The method of Claim 30 further comprising the steps of:

detecting ablated material on the device; and

selectively moving the stage to form a desired pattern of ablated material on the device responsive to the detection of ablated material.

32. The method of Claim 24 wherein the steps of providing the first and second organic layers, and the steps of selectively removing are carried out in a moisture controlled environment.

33. In a method of forming an organic light emitting device having subpixel strips that include organic and hole injector material and that are adapted to emit light of

different wavelengths, the improvement comprising the step of selectively ablating organic and hole injector material from said device in order to form said subpixel strips.

34. A laser ablation system comprising:

a chamber for isolating a work piece in a controlled ambient;

means for controlling the amount of moisture in said chamber;

means for controlling the location of the work piece in said chamber;

means for focusing laser light on the work piece in said chamber;

means for detecting the location of ablated material on said work piece in said chamber; and

means for removing ablated material from said chamber.

35. The system of Claim 34 wherein said means for controlling the location of the work piece is adapted to control work piece location responsive to signals received from said means for detecting the location of ablated material.

36. The system of Claim 34 wherein the means for controlling the location of the work piece comprises a stage adapted to move along any of three perpendicular axis.

37. The system of Claim 34 wherein the means for removing ablated material comprises a suction source outside of the chamber connected to a suction nozzle inside of the chamber.

38. A method of providing light emitting subpixels in an organic light emitting device comprising the steps of:

providing a substrate with an overlying hole injector layer;

providing a lower layer of organic material on the hole injector layer;

providing an upper layer of electrically conductive material overlying the lower layer;

selectively ablating portions of the upper layer such that a portion of the lower layer is exposed;

selectively removing portions of the lower layer such that a portion of the hole injector layer is exposed and light emitting subpixels are formed from a remaining strip of electrically conductive material overlying a strip of organic material.

39. The method of Claim 38 wherein the step of selectively removing portions of the lower layer comprises the step of selectively ablating portions of the lower layer.

40. The method of Claim 39 wherein the step of selectively ablating comprises pulsed laser ablation.

41. The method of Claim 39 further comprising the step of suctioning ablated material during the step of selectively ablating.

42. The method of Claim 39 further comprising the steps of:

monitoring fluorescence emission in the vicinity of ablation during the step of selectively ablating; and

controlling ablation responsive to changes in the monitored fluorescence emission.

43. The method of Claim 42 wherein the step of controlling ablation comprises the step of selectively moving the substrate with overlying hole injector, lower, and upper layers.

44. The method of Claim 42 further comprising the step of filtering monitored fluorescence emission to reduce detection of laser light by a means for monitoring fluorescence emission.

45. The method of Claim 39 wherein the step of selectively ablating includes the step of selectively moving the substrate with overlying hole injector, lower, and upper layers.

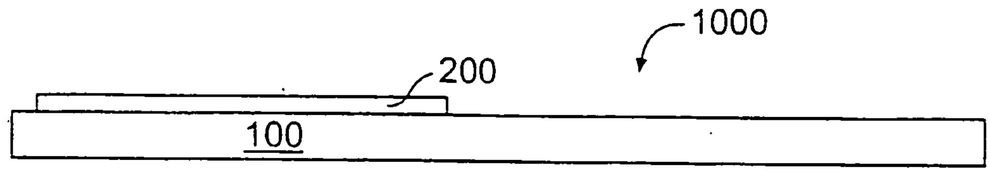

FIG. 1

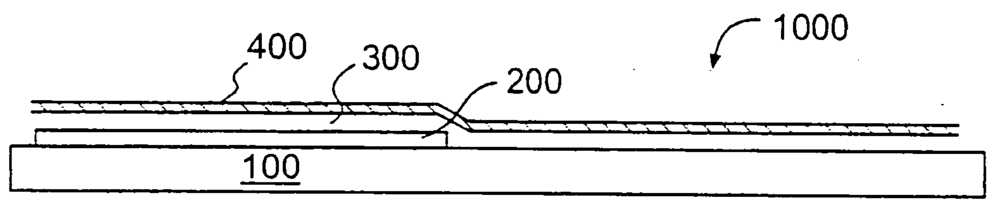

FIG. 2

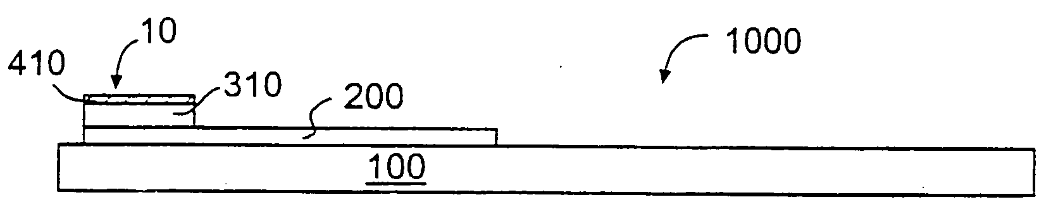

FIG. 3

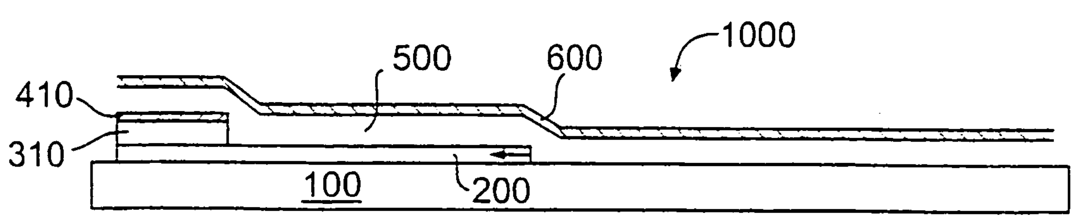

FIG. 4

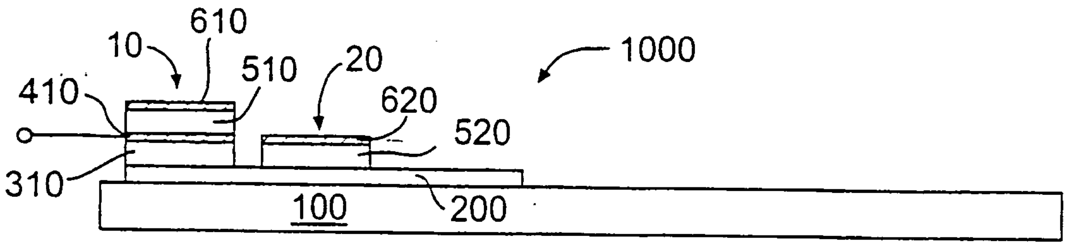

FIG. 5

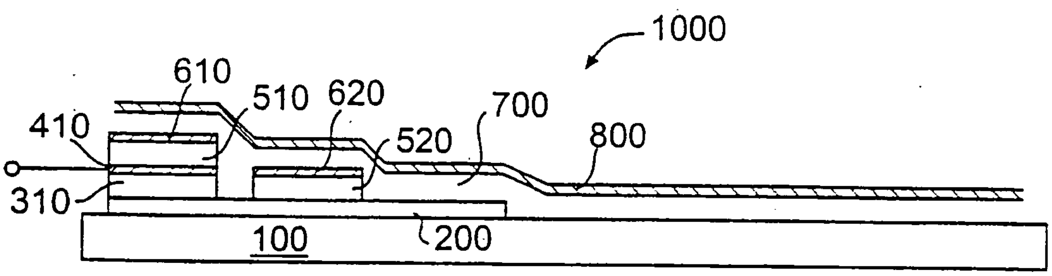

FIG. 6

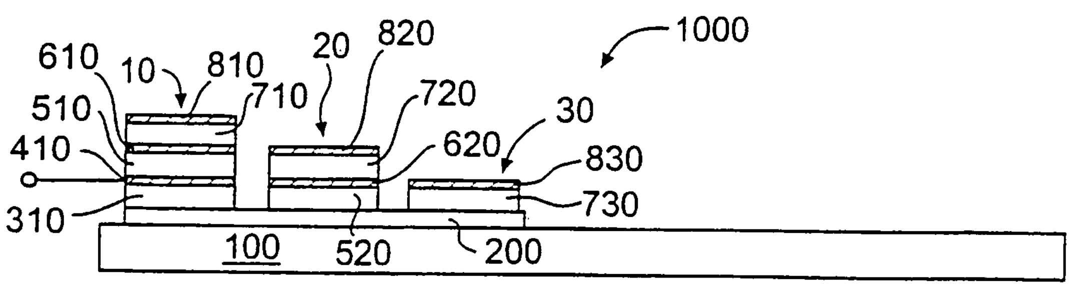

FIG. 7

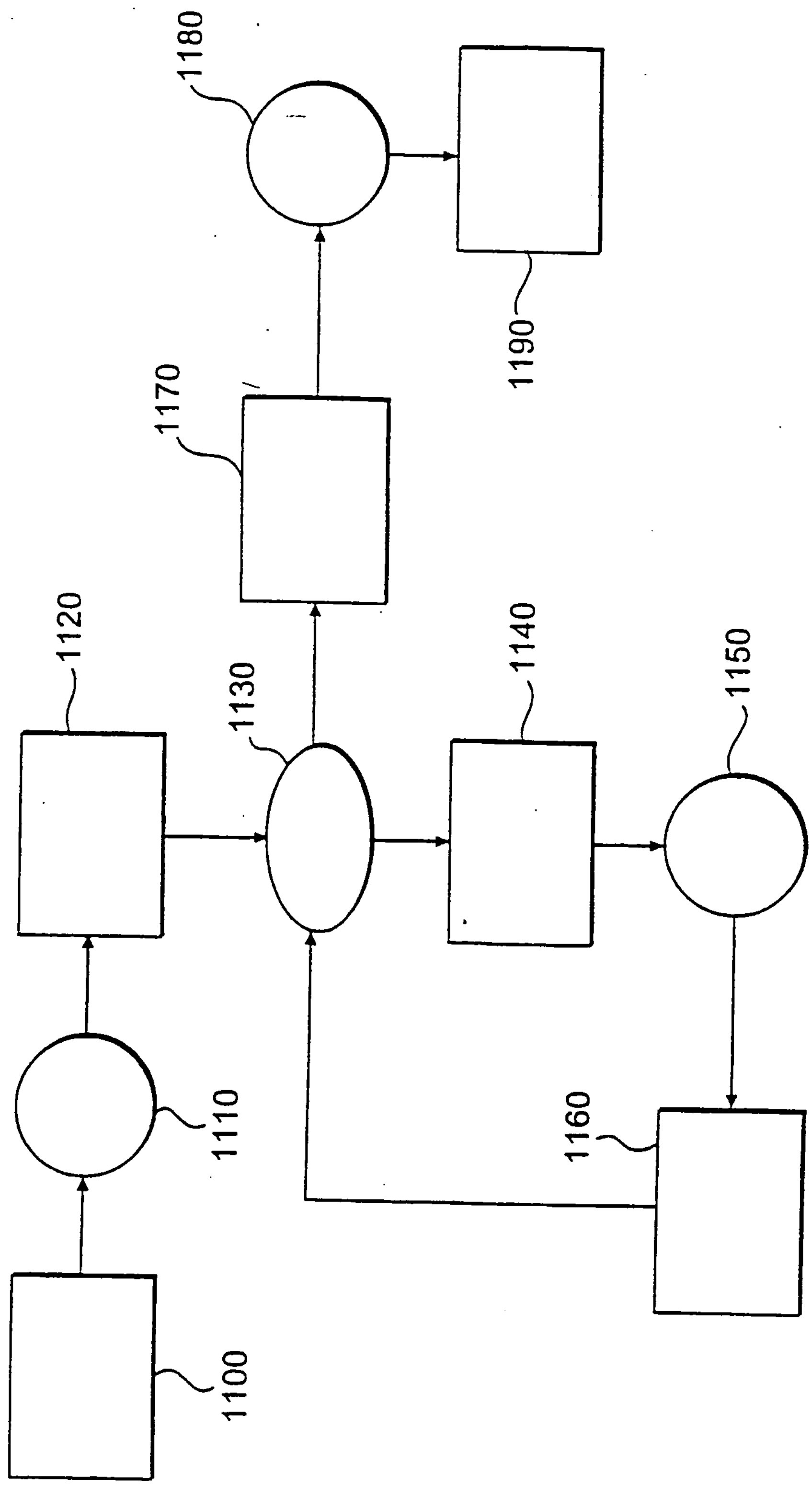

FIG. 8

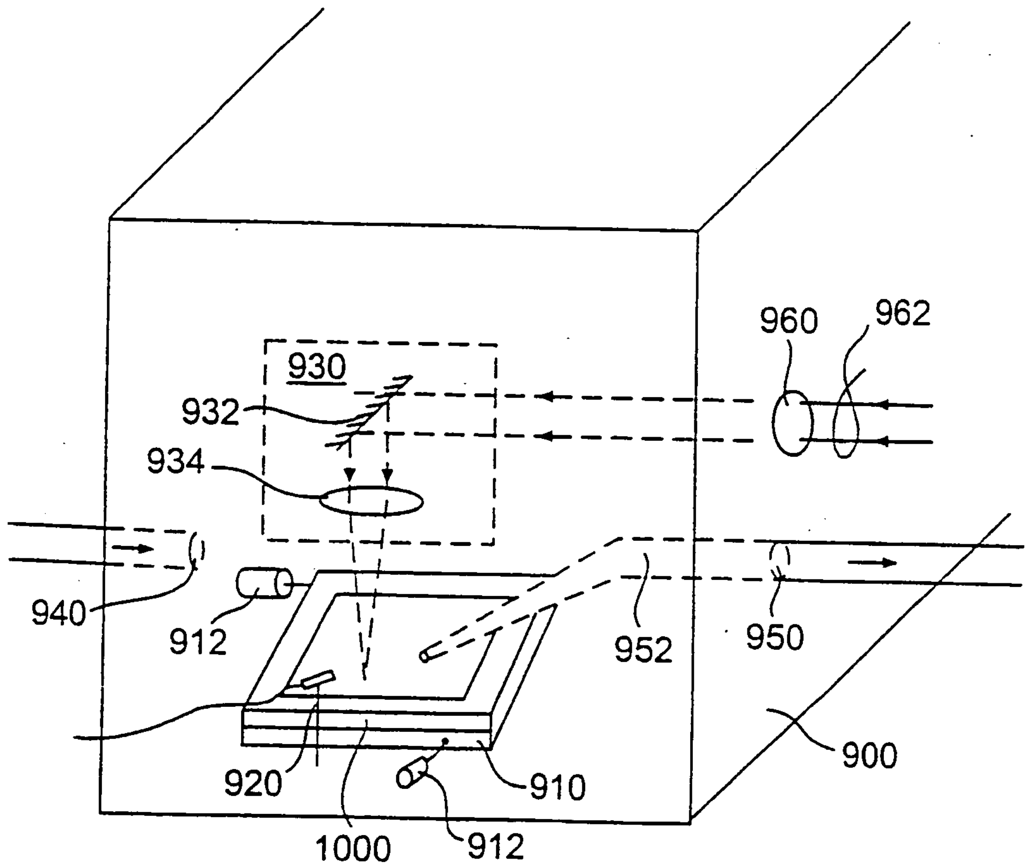

FIG. 9

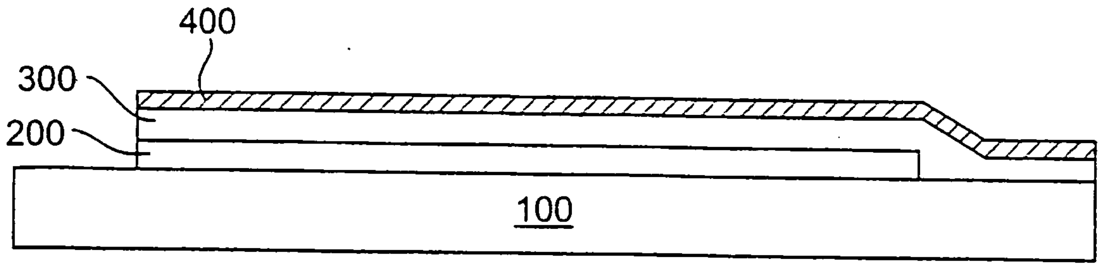

FIG. 10

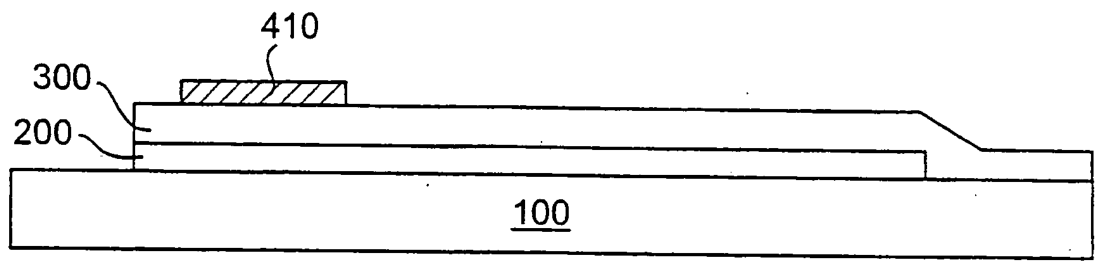

FIG. 11

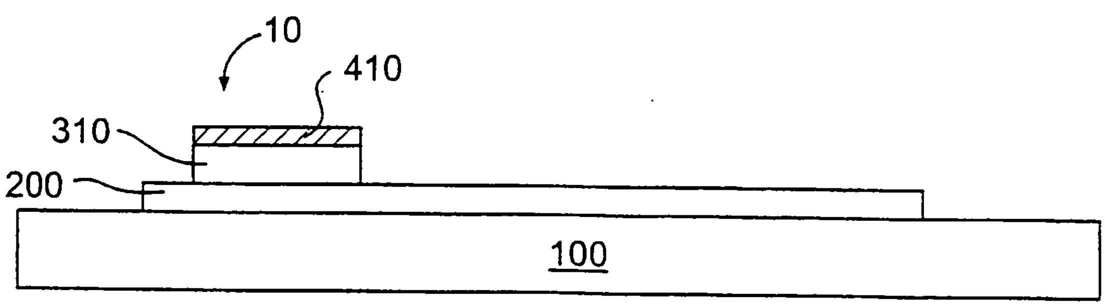

FIG. 12

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US98/13633

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :HO1L 33/00
US CL : 257/40
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 257/40, 88, 89 ,103; 345/82, 83 ; 348/802

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Science Server

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS
Laser ablation and multicolored OLED

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,294,870 A (TANG et al.) 15 Mar 1994, see entire document.	1-45
A,P	US 5,757,026 A (FORREST et al.) 26 May 1998, see entire document.	1-45

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

10 AUGUST 1998

Date of mailing of the international search report

24 SEP 1998

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